Internet of Things (IoT)-Enabled Accountability in Source Separation of Household Waste for a Circular Economy in China

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Abstract

Source separation is regarded as a best practice for sustainable waste management, which is essential for a transition to a circular economy to recover value from waste. However, its implementation in China has faced many difficulties which are primarily inherent in the public's behaviour towards source separation of household waste. Based on multiple cases of innovative use of the Internet of Things (IoT) technologies in China in recent years, this study establishes the concept of IoT-enabled accountability in household waste source separation by utilising the lens of accountability theory. Moreover, this research advances several propositions on the multiple dimensions of accountability mechanism to influence user behaviours. The study's findings provide guidance to governments, technology providers and waste management organisations on the use of IoT-based technological solutions for sustainable waste management. It stimulates future research on the use of IoT technologies in managing people's behaviour in a range of contexts beyond waste management alone. The study contributes to the growing literature on smart waste management.

Keywords: Internet of Things; source separation; accountability; sustainable waste management; smart waste management; circular economy

Article Classification: Case Study

Research Highlights:

1. IoT-enabled accountability concept is proposed in household waste source separation.
2. Multiple cases in China prove the effectiveness of IoT-enabled accountability.
3. Propositions are advanced on various dimensions of accountability mechanism.

1. Introduction

Household waste management (HWM) has been a major challenge for governments across developing countries. Population growth, rapid urbanisation, economic development, and rising standards of living in cities have greatly increased solid waste generation across the globe (Minghua et al., 2009), especially in urban areas (Xu et al., 2016). These trends pose challenges, particularly for environmental protection and sustainable development. A possible solution to overcome the challenges is to adopt a sustainable HWM system in line with the cleaner production (CP) concept and circular economy (CE) philosophy. CP approaches aim to contribute to sustainable development by means of increased production efficiencies, improved environmental management, and sustainable societal development (Hens et al., 2018). The CP approaches are key to achieving the CE vision, in which waste is considered a resource for value recovery (Veleva et al., 2017; Farooque et al., 2019b). Both CP and CE have received increasing worldwide attention and feature prominently in Chinese and European governmental policies (McDowall et al., 2017; Hens et al., 2018; Farooque et al., 2019b).

In the context of sustainable HWM, source separation by the person who disposes of the rubbish has been widely accepted as an ethical behaviour (Xu et al., 2017) and best practice for reducing, reusing, and recycling waste (Karim Ghani et al., 2013; Zhang and Wen, 2014b; Yuan et al., 2016). Previous research has analysed and compared various collection systems for source-separated household waste in many developed countries such as Japan (Matsumoto, 2011), Sweden (Dahlén et al., 2007), and Spain (Gallardo et al., 2010; Gallardo et al., 2012). Relevant studies in China have suggested that source separation makes recycling more efficient (e.g., better quality compost and recyclables) (Zhang and Wen, 2014a) and optimises incineration operations (Zhuang et al., 2008). Furthermore, an increased rate of source separation improves the value recovery from waste flows and facilitates a move towards a CE (Ranta et al., 2018).

China, the world's largest generator of municipal solid waste (MSW) (Wang, Y. et al., 2018), has been encouraging source separation of household solid waste (approximately 80% of MSW) through policy instruments and directives (Zhang and Wen, 2014b). In the past two decades, several source separation pilot projects have been carried out in a number of Chinese cities. However, most of these projects have failed except for some very recent projects where accountability mechanisms were integrated through the use of Internet-of-Things (IoT) technologies (Xu, 2017). The extant literature has primarily focused on identifying the factors inhibiting the successful implementation of the earlier pilot projects (Zhang and Wen, 2014b; Zeng et al., 2016; Xiao et al., 2017), instead of understanding the reasons for success in the most recent pilot projects. On the other hand, Knickmeyer (2020) argues that successful implementation of source separation projects require a deeper understanding of public (household) behaviours and attitudes towards ethical approaches to waste separation (Xu et al., 2017). A number of studies have attempted to identify the antecedents (Wang, Z. et al., 2018), influencing factors (Zhang et al., 2017), and key determinants (Xu et al., 2017) of waste sorting behaviours at the individual and household levels. However, the behavioural aspects of accountability and ethics has been largely overlooked.

While there are many ways to establish accountability mechanisms in a given setting, in recent years, the application of IoT technologies has received growing attention (Boos et al., 2013). Despite some implementation barriers, the use of smart enabling technologies, including IoT in waste management, has been identified as one of the pathways towards a CE (Zhang et al., 2019). In this regard, IoT technologies can offer dual benefits: they facilitate the establishment of an accountability mechanism and they can also support the transition towards smart waste management for a CE. No prior research exists, as far as the authors of this paper know, that links household waste source separation (HWSS) with accountability and IoT technologies.

This study aims to conceptualise IoT-enabled accountability in HWSS. Inspired by the recent success of implementing IoT technologies in several HWM projects in China, this study addresses a key question: How do IoT technologies enable accountability in HWSS?

This paper focuses on residential everyday household waste in typical residential communities in Chinese cities, where many families live in apartment buildings managed by an estate management organisation. The following research objectives drive this paper:

RO1: To establish the concept of IoT-enabled accountability in HWSS

RO2: To develop theoretical propositions on the multiple dimensions of IoT-enabled accountability mechanisms in HWSS

This paper adopts a case study approach to answer the research question and to achieve the research objectives. It presents four cases from different parts of China to establish the concept of IoT-enabled accountability in HWSS. By utilising the lens of accountability theory, this study is a major departure from the prior literature which has utilised various behavioural theory lenses (such as the theory of planned behaviour) to predict and explain behaviour required for source separation of household waste rather than focusing on ways of shaping this behaviour. By drawing on the multiple dimensions of accountability as a mechanism, this research advances several propositions to provide specific answers to the "how" type of research question from different perspectives. In addition to offering new theoretical contributions to the literature on source separation, this paper makes important practical contributions by identifying appropriate solutions to challenging HWM problems that occur in China and in other countries. It also provides insights to researchers and policymakers on how to overcome the behavioural challenges in source separation for sustainable HWM through the innovative use of IoT technologies.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature. Section 3 presents the research method and case data. Section 4 conducts case analyses and proposes several propositions on IoT-enabled accountability. Section 5 discusses the research and practical implications before Section 6 concludes the research.

2. Literature Review

2.1 Accountability theory

Accountability theory explains how the perceived need to justify one's behaviours to another party (that has the authority to administer rewards or punishments), causes one to consider and feel accountable for the process by which decisions and judgments have been reached (Tetlock, 1992; Vance et al., 2015). As a result, the likelihood that one will think deeply and systematically about one's procedural behaviours increases significantly (Vance et al., 2015).

According to Vance et al. (2013, 2015), accountability theory proposes four major dimensions of accountability mechanisms: identifiability, expectation of evaluation, awareness of monitoring, and social presence. *Identifiability* is the individual's "knowledge that his outputs could be linked to him" (Williams et al., 1981, p. 309). Hence, individuals modify their behaviours if they believe their identity might be revealed in the process (Reicher and Levine, 1994). *Expectation of evaluation* is the belief that one's "performance will be assessed by another [party] according to some normative ground rules and with some implied consequences" (Lerner and Tetlock, 1999, p. 255). This expectation increases socially desirable behaviours in individuals (Lerner and Tetlock, 1999; Hochwarter et al., 2007). *Monitoring* is the process of watching or tracking an individual user's activities (Griffith, 1993). An awareness of monitoring fosters the expectation of evaluation (Vance et al., 2015). *Social presence* is the awareness of other users in the system (Walther, 1992). It is widely accepted that individuals exhibit increased conformist behaviour in the presence of another person even when that person is not directly present and cannot be observed (Bond and Titus, 1983).

According to Ferris et al. (1995), the source of accountability may be internal or external to the actor. When individuals perceive internal accountability, the obligation to perform certain behaviours is caused by the actor's own commitment to the behaviour. Hence, no formal control mechanism is required and, rather, individuals act out of a sense of personal control (Dose and Klimoski, 1995). Conversely, under external accountability, actors feel responsible and obligated to perform certain behaviours because they are expected to do so by others. Thus, an external control system would be required to satisfy the accountability demands (Erdogan et al., 2004; Merchant and Otley, 2006; Boos et al., 2013).

Insights from control theories suggest that human actors can only be held accountable if they can understand, predict and influence work processes (Grote, 2009). In the case of perceived internal accountability, theories suggest that actors should only be held accountable for outcomes if they had the freedom to choose between two or more alternatives and to act in a chosen manner (Boos et al., 2013). In this way, individuals feel that they have enough control over the situation to achieve the end results (Dose and Klimoski, 1995). In cases of perceived external accountability, however, the expectations must be appropriately structured and explicitly communicated prior to the performance period for actors to assume responsibility (Dose and Klimoski, 1995; Merchant and Otley, 2006). During the performance period, the evaluators monitor reports of what the individuals were being held accountable for. Mitchell (1993) argues that, for accountability to have an influence on behaviour, there is a need to associate a reward or punishment system based on the individual's performance. This would make the evaluation process more meaningful to the actors. Thus, behaviour results from control mechanisms, including perceived accountability (Beu and Buckley, 2001).

2.2 Accountability and IoT technologies

When accountability is used for monitoring and evaluation purposes, IoT technologies are considered to be key enablers of the control capabilities of the actor demanding the accountability (Winthereik et al., 2007; Bose et al., 2009; Boos et al., 2013). The IoT refers to an integrated network of physical objects that are equipped with electronics, software, sensors, actuators, and connectivity functionalities so that they are able to connect and exchange data (Atzori et al., 2010). IoT technologies can generate large amounts of granular and accurate real-time data automatically (Brous et al., 2020), which is very important in the accountability process. For example, automatic identification and data capture (AIDC) technology, one of the key elements in IoT, is able to automatically identify objects without human involvement, in order to collect data (Stojkoska and Trivodaliev, 2017). IoT technologies make certain aspects of the work process -- which previously may have been considered to be inaccessible and opaque -- visible and available for analysis. For example, big data powered by IoT technologies (e.g., sensors and devices) coupled with supply chain analytics can be used to discover new insights for better and faster decision-making based on data that was previously inaccessible or unusable (Zhang et al., 2020). In principle, this characteristic of IoT technologies is well-aligned with the accountability mechanism which attempts to make the invisible visible (Munro, 1996). However, it is important to evaluate the IoT application used for accountability in the first instance, as the extent of control depends on the capacities of the technology in use (Boos et al., 2013).

2.3 Accountability and household waste source separation

Source separation of household waste is considered an effective method for enhancing recycling and minimising waste (Chung and Poon, 2001). According to Gu et al. (2015), the recyclable component of household solid waste may reach up to 89.3%. Hence, increased levels of household-level source separation can facilitate the transition towards CE. Given their huge potential in achieving sustainable development, many developed countries use systematic and integrated waste source separation programs (Xu et al., 2017). However, low recycling rates of household solid waste have been observed and reported in the extant literature (Fan et al., 2019). For example, the cross-country report of MSW in 32 European countries indicates that eight member countries achieved a recycling rate of less than 10%, eleven countries recycle between 10% and 20%, seven countries between 20% and 30%, and only six countries achieve material recycling levels that are higher than 30% (European Environment Agency, 2013). Similarly, the recycling rate in the United States is equivalent to 35.2% (United States Environmental Protection Agency, 2017).

Until now, most efforts (both academic and practical) to improve source-separated collection rate can be classified into two main streams. The first stream has been focused on exploring characteristics of an effective HWSS program, including strategies, methods, practices, and impact assessments (see, for example, Bernstad et al., 2011; Rousta et al., 2015; Eriksen et al., 2019; Pedersen and Manhice, 2020). The second stream has been focused on understanding the behavioural factors affecting household waste separation at source, including public assessing, public awareness, opinion, and attitudes (see, for example, Sekito et al., 2013; Bernstad, 2014; Parizeau et al., 2015; Xiao et al., 2017). However, technology deployment (for example, IoT applications) for improving source-separated collection rate as evident from the recent successful pilot projects has not been reported in the academic literature. It is also argued that household waste separation at source requires considerable behavioural change and effort from individual households (Karim Ghani et al., 2013). This is difficult to achieve in the absence of a reliable accountability mechanism.

The accountability concept has a widespread application across various disciplines, including environmental and social issues that involve multiple stakeholders (Tomasini Rolando, 2004; Parmigiani et al., 2011; Spence and Rinaldi, 2014). Zakaria (2011) suggests that stakeholder engagement has a great potential to influence accountability in complex systems. As a major subset of municipal solid waste management, HWM is a truly complex system with significant environmental and social impacts. It involves multiple stakeholders, including governments, enterprises, non-governmental organisations, waste collectors, residents, and so on (Xu et al., 2015). Therefore, stakeholder engagement and interaction with an effective accountability mechanism become extremely important for the success of HWM source separation projects.

2.4 IoT applications in CE and waste management

In transitioning to a CE, IoT technologies can facilitate the management of restorative and regenerative resource flows. IoT is able to help with the collection of data generated from various sensors such as smart meters so that stakeholders across the value chain can be connected (Pagoropoulos et al., 2017). IoT not only provides real-time data, it reflects the consequences of particular actions by stakeholders. Thus, CE models based on IoT-captured data may be established for evaluation throughout the lifecycle of certain products such as smartphones (Alcayaga et al., 2019). Recently, researchers and practitioners refer to the concept of a 'smart CE', which is enabled by key technologies such as IoT. Kristoffersen et al. (2020) presented a smart circular strategies framework for manufacturing companies using IoT which is used for aligning activities across the CE and information systems. Its capacity for data collection has led to the wide usage of IoT for supporting the CE in terms of system development and implementation (Lin et al., 2019; Rajput and Singh, 2019).

Some real-life cases of adopting IoT in CE for sustainability have been reported. For example, Fatimah et al. (2020) introduced an advanced technology like an IoT-based sustainable CE method from Indonesia for a smart waste management system. IoT technology has also been used in waste management (Hong et al., 2014; Medvedev et al., 2015; Anagnostopoulos et al., 2017) to achieve sustainability in smart cities (Al-Turjman et al., 2019). Arguably, the information collection efficiencies and high levels of data sharing that has been achieved through IoT technology has made feasible data-driven decision-making models. González-Briones et al. (2020) proposed an agent-based IoT platform to encourage citizen participation in recycling tasks through gamification mechanisms. The work was mainly motivated by the lack of a common method of waste management in the European Union. Similarly, 'Heat Wave Mitigation in Métropole de Lyon', reported by Robert et al. (2017), is a recent example of an IoT-enabled smart city. This example is based on the European Union Horizon 2020 program, aiming to improve the interoperability between a number of system components. Kang et al. (2020) discussed the applicability of an IoT-enabled smart collection system to manage household e-waste in the Malaysian e-waste recycling sector. This system improves the efficiency and effectiveness of household waste management in terms of saving time and maximising the utilisation of equipment such as trucks. Centenaro et al. (2016) introduced some IoT scenarios for typical smart city applications in terms of efficiency, effectiveness, and architectural design. Hong et al. (2014) presented an IoT-enabled smart garbage system, piloted in Seoul, the Republic of Korea, for efficient food waste management. The system was capable of exchanging the IoT-captured data using wireless mesh networks, and the data could be analysed for service provisioning. Anagnostopoulos et al. (2017) discussed the challenges and opportunities of waste management in the IoT-enabled smart cities based on a survey study in the city of St. Petersburg, Russia. They focused on IoT-enabled smart devices and proposed a novel framework for waste management. Wen et al. (2018) presented a case study of an IoT network system for restaurant food waste management in Suzhou, China. This system has been running for some years and has achieved significant benefits, including a 20.5% increase in food waste collection.

2.5 Research gaps

A thorough review of the literature suggests that IoT-enabled accountability for sustainable HWSS is an emerging research topic. The following research gaps were identified, which motivated the authors to conduct this research.

1. In the extant literature, HWSS is highly regarded as an effective method for recovering value from waste flows and facilitating the transition towards a CE. Despite an abundance of research on HWSS, the low rate of HWSS is a commonly reported issue in many countries including China, which is the context of the current study. Evidence from very recent pilot projects suggests that technology deployment (i.e., IoT applications) has played a significant role in improving the source-separated collection rate. However, such cases have not been reported in the academic literature.
2. Most of the research efforts to date have been put into predicting and explaining the behaviour required for source separation of household waste. Invariably, the questions such as "what shapes an ethical HWSS behavior" and "how does technology deployment shape an ethical HWSS behaviour" remain unexplored.
3. The majority of the source separation pilot projects carried out in several Chinese cities in the last decade or so have failed to be effective except for some very recent projects where accountability mechanisms were integrated through IoT technologies. However,

IoT technologies' role in enabling accountability in HWSS remains unclear in the literature.

3. Research method and data

Figure 1 outlines the methodological procedures of the research. This study adopts a qualitative research approach using multiple case studies for two reasons. First, there is scant research exploring IoT-enabled accountability in HWSS, although IoT technologies and accountability have been studied separately. In focusing on how IoT technologies enable accountability in HWSS in China, this study aims to contextualise, interpret and understand the inner mechanism through inductive reasoning in order to generate a new theory (Yilmaz, 2013). Qualitative research methods, such as multiple case studies, are appropriate for this under-investigated topic, as case studies can "present data of real-life situations and provide better insights into the detailed behaviour of the subjects of interest" (Zainal, 2007, p.5). Second, HWSS has emerged as a major challenge for many countries across the world, including developed countries such as Japan, Germany, and the United States. Since 1997, China has attempted to implement HWSS systems, but most of the pilot projects had achieved poor results (Zhang et al., 2008), except for some trials of IoT smart HWSS systems in the last four years. Given the limited evidence of successful HWSS projects in China to date, there is a need to adopt a more exploratory approach, for which a qualitative method is more suitable.

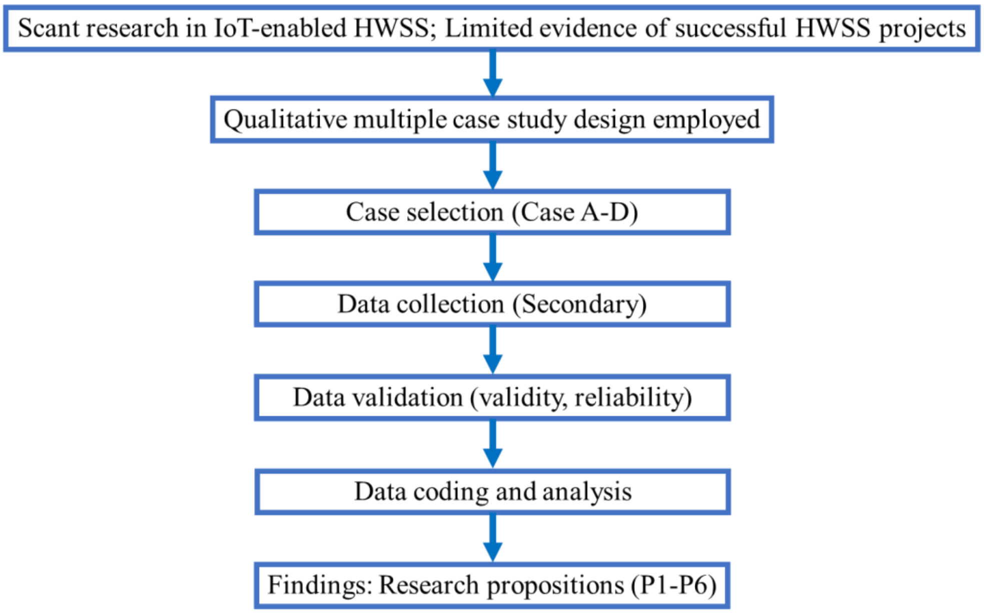

Figure 1: Schematic diagram of research methodology

Following the replication methodological logic, multiple case studies can either predict similar case results to strengthen the emerging theory, or generate contrasting results to extend theory (Yin, 2011). As advised by Eisenhardt (1989), the researchers selected four cases which were sufficient for generalising empirical findings while avoiding the data complexity resulting from too many cases.

3.1 Case selection

Case selection was purposive and theoretically directed (Strauss and Corbin, 1998) based on the following criteria: (1) the geographic setting: considering China has a vast territory, cases were selected to represent major areas including the east coast (Case A), the capital city in the northern area (Case B), the western area (Case C), and the southern area (Case D); (2) successful outcomes: the researchers selected cases which have successfully strengthened accountability; (3) the system had to be in practice for a minimum of three years. Table 1 summarises the main characteristics of the four cases. Profiles of each case are provided below.

Case A. In 2012, a source separation project started in the Huachuan residential community, Ningbo. Despite source separation promotion and education campaigns, a breakthrough in changing the residents' waste disposal behaviours did not occur until IoT technology was introduced. Since 2016, 2D barcodes unique to each household in the residential community have been printed on all rubbish bags. A database was established to track the user of each rubbish bag. Every morning at 8 am, a community worker visits the rubbish collection point to conduct a sampling check of about 50-80 rubbish bags on source separation. He uses an app installed on a smartphone to scan the 2D barcodes on the rubbish bags to identify the owners. If any noncompliance is identified in rubbish sorting, the community management acts to re-educate the noncompliant users. Some volunteers from the community have also been actively involved in educating and assisting their neighbours in source separation. The IoT-enabled system rewards credit points to compliant residents. The community management regularly gives awards to the best-performing households and publicises the names of winners. Because of the accountability achieved through the innovative use of IoT technology, the source separation rate has steadily improved, reaching above 70% in less than two years.

Case B. An IoT source separation project started at Xinyi Homes residential community, East-City, Beijing in 2018. Governmental organisations such as street agencies, administrative offices, and enforcement departments work together to advance the project. They run education campaigns to promote the source separation project by using an IoT system for different users: smartphone users can download a "separation" application to register their identifications (ID) while non-smartphone users can register their IDs from a local street agency and obtain a barcode card. When disposing of rubbish, registered users need to scan their ID barcodes on the collection station to open the correct bin as per the waste type. Then the system weighs the waste and rewards the users with credit points. Non-registered users can press a button to dispose of their rubbish but they have no way to receive reward credit points. The system also has other functions, including full-load warning, multi-function display, an intelligent placement device, an anti-pinch nozzle, temperature detection, positioning, LCD publicity screen, ozone sterilisation, and an external cigarette box. By applying both an administrative approach and a smart IoT system, Beijing City has been able to conduct online supervision and monitoring of waste separation activities successfully.

Case C. An IoT-enabled smart recycling system called "Panda" has been on trial in a residential community in Chengdu, Sichuan since November 2018. The "Panda" has three application layers: the front-end layer, the middle layer, and the back-end layer. The front-end layer enables residents to use a smartphone to scan a barcode on the recycling station for disposing sorted waste. Residents can get cash rewards based on the correctness of waste sorting and the weight of sorted waste. The middle layer coordinates garbage collection and transportation activities. The back-end layer consolidates and centralises the further processing of sorted waste to recover value. The whole system can help residents to sort garbage based on material (i.e. paper, plastics, metal, and clothing) and it also customises collection projects based on the demand and arranges pick-ups from home. The innovativeness and intelligence of the system have been well recognised by the residents. The local street neighborhood committees have been coordinating and supporting the project.

Case D. Since August 2017, Luohu, Shenzhen City has deployed 63 smart IoT machines in 61 residential communities. Before disposing household waste, a resident needs to verify their identity by using smartphone to scan a 2D barcode on the machine (a non-smartphone user can scan his/her low-carbon card from the system to verify their identity). Then, the machine will open its collection door. The smart equipment can recognise the waste type (glass, metal, plastics, paper, textile, kitchen waste, and other) and weigh the waste and reward the compliant resident with credits. The credits earned can be used for shopping in the local markets and can even be withdrawn as cash from local banks. The system runs on a cloud-based platform. It can monitor whether the IoT collection containers have been fully loaded or not. The fully loaded IoT containers can automatically send signals to the control centre for arranging timely collection. It can also improve route management by tracking how trucks collect the waste from stations.

Table 1. Summary of case profile

Case	Role of stakeholders such as local council, community, and volunteers	Waste classification	Accountability for source separation	Positive and negative incentives	Results
Case A: Ningbo, Eastern China (2016—)	• Implement "Regulations on the Management of Domestic Wastes in Ningbo." • Train residents to improve their awareness of the significance of waste sorting and to cultivate the habit of waste sorting. • Educate and re-educate noncompliant users based on sample checking and inspection.	• Hazardous • Recyclable • Kitchen waste • Other	• Each household has a unique 2D barcode on the rubbish bags which can be traced back. • Inspectors select 50-80 bags randomly every day to check whether waste is correctly sorted or not. • Inspectors trace back the noncompliant residents by scanning the 2D barcode on the rubbish bags. • Community workers and volunteers help educate and assist the residents in source separation.	• Invest in infrastructure and provide free rubbish bags with 2D barcodes. • Educate, criticise, and even fine non-compliant residents up to RMB200. • Regularly reward the best-performing households and publicise the names of winners.	• More than 70% of household waste has been separated properly. • More than 75% of residents have actively participated in the project.
Case B: East-City Beijing Capital city Northern China (2018—)	• Implement "Beijing Municipal Solid Waste Management Regulations Amendment". • Government organisations such as street agencies, administrative offices, and enforcement departments work together to promote and enforce the project. • Run education campaign for smartphone users and non-smartphone users.	• Hazardous • Recyclable • Kitchen • Other	• Residents can register as IoT HWSS users by using a smartphone app, or getting a barcode card from the local neighbourhood committee; then scan their smartphone or barcode card to dispose waste. • Waste collectors can receive the full-load warning to empty the containers and to transport waste to treatment centre in a timely fashion. The temperature detection, ozone sterilisation, and an external cigarette box can effectively keep the container from burning due to cigarette butts.	• Fine up to RMB200 for non-compliant residents. • Reward credit based on the correctness of waste sorting and weight of sorted waste.	The online supervision and monitoring system have been set up successfully.
Case C: Sichuan, Western China (2018—)	• Implement "Chengdu Domestic Waste Management Regulations" • Street neighbourhood committee and Longquanyi District coordinated and supported the project.	• Paper • Plastic • Metal • Clothing	Three application layers: • The front-end layer for source separation links residents with the discarded waste. • The middle layer links collectors with waste collection and transportation. • The back-end layer is for waste treatment and value recovery.	• Fine up to RMB200 for non-compliant residents. • Reward residents cash/credit based on the correct disposal and weight of sorted waste.	The household waste recycling rate now reaches around 35%. The system has significantly improved the awareness of source separation of household waste. It has cultivated in residents a good habit of separating household waste.
Case D: Luohu Shenzhen Southern China (2017—)	Luohu District council has deployed 63 smart recycling systems in 61 residential communities.	• Glass • Metal • Plastic • Paper • Clothing • Kitchen waste • Other	• Use smartphone app or register for a low-carbon ID card for personal identification. The smart system weighs the sorted waste and awards credits accordingly to the resident's account. • Its cloud-based platform can monitor in real-time source separation activities, waste collection truck utilisation, and aid better decision making in waste collection activities. • Data in the system inform policymaking and management decisions.	• Combination of legal penalties and rewards by implementing "Shenzhen City Domestic Waste Classification and Reduction Management Measures." • Criticise, educate, and fine non-compliant residents up to 200RMB. • Reward residents low-carbon credits based on the correct disposal and weight of sorted waste.	Residents were guided to classify waste correctly. The rewards motivated many residents to participate in source separation with enthusiasm; good results were achieved in a short time period.

3.2 Data collection, validation, and analysis

This research uses secondary data. Secondary data has its disadvantages because it has been collected by others for different purposes but for the context of this study, it offers relevant information to address the research questions posed and it enables a means of understanding and explaining the research problem at hand (Ghauri and Gronhaug, 2005) The objective of exploring how IoT technologies enable accountability in HWSS is served by the data drawn from over ten reliable sources for each case (see the supplementary data attached). The collected data elaborate the entire process flow and illustrate how IoT systems can compel the accountability of residents and collectors in HWSS. The data also show how stakeholders, such as the government and its respective organisations, help to train, educate, re-educate, reward and/or punish to enforce the accountability of residents in IoT HWSS systems.

Validity and reliability tests have also been performed in this study. In terms of constructive validity, multiple sources of evidence were applied to triangulate the data, including webpages describing the IoT systems, and of governmental and semi-governmental organisations, in addition to catalogues and magazines articles (Ghauri and Gronhaug, 2005). The draft report was also reviewed by four researchers. Internal validity was enhanced through (1) a clear research framework (refer to Figure 1); (2) discussing the findings among the researchers; (3) triangulating to confirm the emerging findings; and (4) refining the theoretical orientation of the research. External validity is improved by (1) rationale for the case selection (refer to 3.1); (2) details of the case study context; (3) the case study being guided by the accountability theory (refer to section 2.1); and (4) comparing across the four case studies. The development of the case study database (refer to the supplementary data attached) also serves to enhance the reliability of this study's findings.

The data coding and analysis proceeded through two main phases. Firstly, the researchers searched more than ten secondary data sources for each case and scrutinised them to identify the conceptual themes that emerged. Then, the researchers with Chinese and English language skills analysed the descriptive transcripts and coded for conceptual content on the identified themes including accountability, reward, and punishment. Data analysis was an iterative process between reviewing theoretical concepts and identifying patterns in the case data. Finally, the results were analysed and synthesised into case findings.

4. Case analysis and research propositions

The four IoT HWSS cases (A-D) have been analysed and Figure 2 provides an overview how the six resulting propositions have been induced and synthesised into a theoretical framework. The framework integrates multiple dimensions of IoT-enabled accountability and depicts the relationships between the accountability dimensions. The detail of the induction is described as follows.

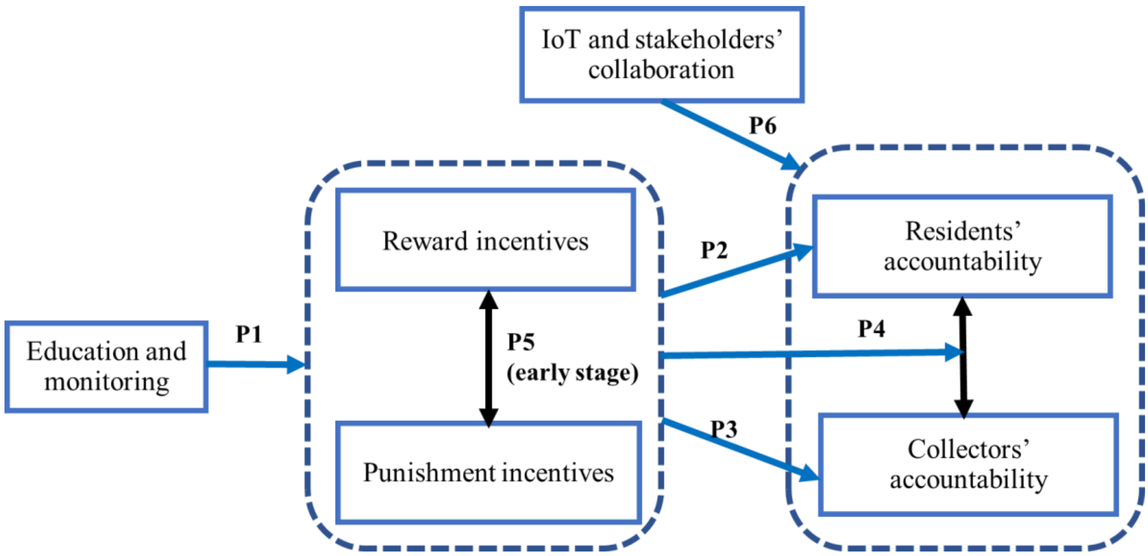

Figure 2. Theoretical framework of IoT-enabled accountability

Although the four cases (A-D) differ from each other in their location, sample populations, history, and the technologies used, there are some commonalities which can be drawn for an accountability related study (Refer to Table 2).

Table 2. **Comparison of the selected cases**

Commonalities
·Implement local government Regulations on the Management of Domestic Wastes. ·Train residents to improve the awareness of the significance of garbage sorting and to cultivate the habit of waste sorting. ·Educate and re-educate the noncompliant users based on sample checking and inspection. ·All stakeholders work together to promote and enforce the project. ·Fine up to RMB200 for non-compliant residents.

	Differences			
Case	**Waste classification**	**Technology application**	**Processing**	**Reward**
A (2016—)	hazardous, recyclable, kitchen waste, other	Preliminary IoT system: hand scan 2D barcode on rubbish bag	Government invests in infrastructure and provides free rubbish bags with 2D barcodes. Each household has a unique 2D barcode on the rubbish bags which can be traced back. Inspectors select 50-80 bags randomly every day to check whether waste is correctly sorted or not; Inspectors trace back the noncompliant residents by scanning the 2D barcode on the rubbish bags.	Regularly gives rewards to the best-performing households and publicizes the names of winners.
B (2018—)	hazardous, recyclable, kitchen waste, other	Advanced IoT system	Residents can register as IoT HWSS users by using a smartphone app, or getting a barcode card from the local neighbourhood committee; Residents need to scan their smartphone or barcode card to dispose waste; Waste collectors can receive the full-load warning to empty the containers and to transport waste to treatment centres in a timely fashion. The temperature detection, ozone sterilisation, and an external cigarette box can effectively keep the container from burning due to cigarette butts.	Reward credit based on the correctness of waste sorting and weight of sorted waste.
C (2018—)	paper, plastic, metal, clothing	Advanced IoT system	Three application layers: the front-end layer for source separation links residents with the discarded waste, the middle layer links collectors with waste collection and transportation, the back-end layer is for waste treatment and value recovery. Residents need to scan their smartphone or barcode card to dispose waste.	Reward residents cash/credit based on the correct disposal and weight of sorted waste.
D (2017—)	glass, metal, plastic, paper, clothing, kitchen waste, other	Advanced IoT system	Use smartphone app or register for a low-carbon ID card for personal identification. The smart system weighs the sorted waste and awards credits accordingly to the resident's account. Its cloud-based platform can monitor in real-time source separation activities, waste collection truck utilisation, and aid better decision making in waste collection activities.	Reward residents low-carbon credits based on the correct disposal and weight of sorted waste.

The four cases involve different levels and complexities of technology usage, however, all of these cases share a common denominator: the necessity of education and monitoring from governmental workers and volunteers to implement IoT HWSS systems. Since IoT HWSS systems are new in their philosophy, design, processing, and administration, residents need to become familiar with the system they are required to use. Residents are compelled to change their old habits and to form new habits in using the IoT HWSS system. Education and re-education can help residents to become familiar with the disposal processes of the new system and to correct wrong behaviour. Meanwhile, monitoring can affect past behaviour, attitudes, normative beliefs, and perceived control (Webb et al., 2014). From an accountability theory perspective Vance et al. (2013, 2015), the identifiability factor could encourage residents to better educate themselves about the new IoT system and related administration; the monitoring from stakeholders can foster the expectation of evaluation and related social presence to modify the residents' disposal behaviour. Therefore, education and monitoring are the necessary preconditions for using IoT to establish accountability. Thus, the following proposition is proposed.

P1. Education and monitoring of residents are preconditions for IoT-enabled accountability in household waste source separation (HWSS).

The success of HWSS depends greatly on its two responsible stakeholders (residents who dispose waste, and collectors who transit the waste) at the front end. Since the traditional HWSS system has its innate imperfections with pre-separation collector bins, the system's capacity to succeed relies heavily on residents' accountability to put the waste into the right bins. Waste that is incorrectly sorted may be the result of certain behaviour-related attributes, such as carelessness, ignorance, lack of education, etc. Moreover, a lack of effective onsite supervision and administrative systems to incentivise the desired behaviours also undermine attempts to hold residents accountable, which leads to the poor levels of performance reported. A case study of Suzhou, China indicated that 43% of the respondents thought they knew how to source-separate waste, but only 29% of them actually source-separated waste accurately (Zhang and Wen, 2014b).

A system enabled by IoT technologies, however, can avoid such flaws. With IoT-enabled HWSS, the resident needs to scan their family ID-related barcode, or QR code, to open the correct bin in order to dispose of the waste. In this way, the IoT system can easily link the residents' identities with their waste disposal behaviours, thus improving their identifiability (Williams et al., 1981) which, according to accountability theory (Reicher and Levine, 1994), shapes their behaviour. The IoT system can immediately detect if the waste has been disposed of accurately. Also, it simultaneously records the disposal data such as disposal time, weight, category, accuracy, as well as the corresponding reward or credit. All information can be checked at the IoT HWSS online system by residents using devices such as smartphones and computers. Meanwhile, the internal motivation of residents to sort waste can be reinforced by a reward system: the correct separation behaviour can gain credits as a bonus. Consequently, a reward system can train and educate residents to improve their awareness of expectations of evaluation (Vance et al., 2015) and commitment (Ferris et al., 1995). With the passage of time, residents' waste disposal behaviour can be changed, and their accountability can be strengthened. This leads to the following proposition.

P2. IoT systems can enable residents' accountability in HWSS by changing their waste disposal behaviour.

The other key entity in a HWSS system is the waste collection stations ("collectors"). In the traditional HWSS system, the collectors receive the discarded waste at temporary depots and passively wait for instructions or orders from the waste management company to empty the bins and redirect the waste for appropriate treatment. Since this traditional HWSS system was designed based on a stationary concept -- that is, to collect waste in a pre-set geographic area at a pre-set time -- it lacks the flexibility to deposit and clear the waste on time. Meanwhile, the collectors' capacity remains underutilised or, at other times, insufficient to meet the actual HWSS requirement in the clearance cycle. Since the amount of waste produced is significantly affected by many factors such as seasons, weather, festivals, parties, holidays etc., the traditional system suffers from low efficiency, poor performance, delayed operation, and/or under-optimisation. To artificially maintain the HWSS accountability levels, the collectors' bins in some communities are even locked when administrative supervision is not available.

The IoT-enabled HWSS system, however, has been designed to have the dynamic ability to detect the real-time fill level information of rubbish bins and to notify the backend waste management company to clear the bins in time. The backend operations can also analyse each collector's information and optimise the collection and transport capacity in the whole area. With the real-time data and monitoring mechanism provided by the IoT systems, the collectors have no excuse of not achieving a high level of flexibility and efficiency in their waste collection operations. According to accountability theory, such visibility in the operations enhances the expectation of evaluation which, in turn, increases the collectors' accountability (Boos et al., 2013). Therefore, the following proposition is proposed:

P3. IoT systems can augment the collectors' accountability in HWSS by providing real-time visibility in their operations.

The accountability of the residents and the accountability of the collectors interact with each other. Firstly, the residents' accountability is the prerequisite for the collectors to achieve their accountability. If the residents do not feel accountable in correctly sorting their waste, the collectors will not be able to realise their accountability, regardless of how advanced and smart the systems are. Indeed, there have been cases of residents whose lack of accountability have directly impacted on the collectors' accountability. For example, many rubbish bins are burnt in China each year due to irresponsible disposals of cigarette butts[1]. The collectors, however, can also be regarded as a type of external source of accountability for the residents (Ferris et al., 1995). The accountability of the collectors is the necessary condition for the residents to achieve their accountability as it prompts residents to feel comfortable and confident that they can control the waste disposal results (Dose and Klimoski, 1995) given an increase in the expectation of evaluation and social presence to satisfy their demands of accountability (Boos et al., 2013).

The success of HWSS systems relies on the positive interactions between residents and collectors and their respective accountabilities. While traditional systems fail to achieve this interaction because of their limitations in system design, IoT HWSS systems are able to promote the interaction based on their inherent smart systems. When residents discard the waste into collectors' bins, IoT HWSS systems can detect the accuracy of the sorting from the residents. IoT HWSS systems can also measure the real-time situation of the fill rate of collectors' bins; that is, when the "bins full" warning is triggered and sent to the control centre, the centre will assign the waste clearing team to empty the bins in a timely manner. Thus, residents can dispose of their waste without any limitations related to time of disposal or bins' capacity. In fact, the less internal accountability is present in the residents, the greater the need to use external accountability, which can be effectively enabled by IoT. Based on the above discussion, the following proposition is proposed:

P4. IoT systems can lead to positive interactions between the residents' accountability and the collectors' accountability.

[1] http://news.stcn.com/2019/1109/15486935.shtml (9 Nov 2019, Reporter: Yahua Sun)

Nearly all the residents understand the importance and significance of HWSS to the environment, but this does not necessarily translate to their correct separation and disposal of waste since good intentions may be forgotten (Verplanken and Faes, 1999). Since habits are forms of goal-directed automatic behaviour (Aarts and Dijksterhuis, 2000), the waste disposal habits of residents can be changed to achieve certain goals. Behaviour is the reaction of stimulation from the external environment (Weiner, 2010; Gneezy et al., 2011). If the result from the incentive is beneficial to oneself, the behaviour will be strengthened and repeated; if not, the behaviour will fail to be sustained. Although punishment can prevent the enactment of undesirable behaviours, it cannot encourage desired behaviours and can instil resistance and boredom in the punished (Trevino, 1992). Rewards, however, can increase one's intrinsic motivation and sense of self-determination, depending on what is required of one to perform (Eisenberger et al., 1999).

Reward and punishment incentives, however, can only work when there is support from all stakeholders, in this case, the government, local council bodies, the community, and the residential committee. This is because reward incentives need strong financial support from the government. For example, Shenzhen spends more than 60 million RMB in rewards each year[2]. Equally, punishment mechanisms can only work when the system is supervised and implemented by all the stakeholders involved.

Reward and punishment incentives are less effective if they operate in isolation -- a successful system normally involves both dimensions to simultaneously reward appropriate and punish inappropriate behaviour (Litzky et al., 2006). If the lens of accountability theory is applied here, the moulding of desired behaviours by residents can be explained in the following way: positive and negative incentives instil recognition in residents that their disposal behaviour has

[2] http://news.stcn.com/2019/1109/15486935.shtml (9 Nov 2019, Reporter: Yahua Sun)

consequences (Williams et al., 1981); residents' expectations of having their disposal behaviour continually evaluated are raised and normalised (Lerner and Tetlock, 1999); and finally, the desired behaviour is reinforced through the perceived social presence of others (Bond and Titus, 1983). Indeed, the four cases (A-D) examined in this study proves that a combination of reward and punishment systems in IoT-enabled accountability is more effective for motivating the public to participate in source separation of household waste, and to form correct behaviour, especially in the early stages. One testimony is as follows:

> *"The close combination of the rules and reward incentives is a highlight of our waste sorting work in Luohu District, and it is also a magic weapon for us to achieve the goal of waste sorting work."*
>
> *Wenzhi Lin (Deputy Director of Luohu District Urban Management Bureau, Case D)*

Once residents acquire the desired behaviour of correctly sorting waste, incentives may play a less significant role but can still reinforce the desired behaviour. Therefore, the following proposition is advanced:

> P5. IoT-enabled accountability can be most effective by applying both positive and negative incentives in the early stage implementation. Incentives, however, may be gradually phased out once residents have formed the habit of sorting rubbish.

The accountability of the residents, however, may weaken if they were to perceive a reduction in the system's capacity to identify users, or if the level of ongoing scrutiny that they have come to expect is somehow lessened over time (Vance et al., 2013). The continuation of an accountability mechanism to shape and sustain desired behaviours relies on the collaboration of all stakeholders, including administrative supervision from the national government, city council, community, non-governmental organisations, media organisations, and volunteers. In the four IoT-enabled source separation projects examined in this paper, the government has played a central role, even though the projects are established in different regions of China with different economic and cultural backgrounds. When implementing IoT-enabled source separation in a residential community, only the local government and its agencies have the authority, resources, and power to employ its legal and administration system to enforce compliance. After an IoT-enabled system is in place, there are on-going requirements to educate residents, to monitor the participation of residents, and to give rewards and penalties to sustain the positive behavioural change in the public. The effort involved in managing and administering this programme may initially form and consolidate the residents' accountability for an initial period but long-term accountability requires an IoT system to make the HWSS work sustainable and durable. This leads to the next proposition:

> P6. To sustain a source separation programme over the long term, all the involved stakeholders must cooperate to play their roles; IoT can facilitate such efficacy by providing a platform to operationalise the processes and to enable accountability effectively and efficiently.

5. Discussion

5.1 Theoretical implications

This study makes a theoretical contribution by establishing the concept of IoT-enabled accountability and its multiple dimensions. From a systems perspective, a traceability service offers great support to establish accountability. In the extant literature, most of the traceability applications are associated with non-human objects. However, waste separation behaviour requires effort from individuals as proper household waste separation is essential for the achievement of a CE (Stoeva and Alriksson, 2017). This is where the accountability principle becomes important as it deals with human participants and often incorporates rewards and penalties to reshape behaviour. Although the importance of people's behaviour is widely recognised (Zhuang et al., 2008; Bernstad, 2014; Zhang and Wen, 2014b), little research has investigated the role of IoT in bringing about a behavioural change in a source separation and CE context. This study advances the field by moving beyond IoT-enabled traceability to IoT-enabled accountability.

IoT-enabled accountability is not only useful for waste management, but for any contexts where it would be beneficial to hold human participants accountable. For example, IoT has been used to track the location and speed of automobile vehicles. Applications can be developed for monitoring drivers, holding them accountable for irresponsible driving behaviours. On a manufacturing shop floor, IoT can be used to trace which workers perform certain process steps. If defects and quality issues are a concern, accountability applications can be developed for monitoring individual workers' quality performance. There is great potential for IoT technology providers to market IoT-enabled accountability applications, and future research can explore innovative marketing mechanisms.

The IoT-enabled source separation mechanism presented in this research contributes to the rapidly-growing literature on smart waste management. Smart waste management is a relatively new concept (Zhang et al., 2019) that offers a promising future but also faces many challenges (Anagnostopoulos et al., 2017). An IoT-enabled source separation mechanism could overcome a major challenge that is prevalent in many countries: specifically, the major obstacle to source separation posed by the culture and the public's behaviours. This is in line with the findings of Zhang et al. (2019) that a lack of environmental education and a culture that is not oriented towards environmental protection is a key cause of barriers to smart waste management for a CE in China.

5.2 Practical Implications

The general propositions advanced from the case studies on IoT-enabled accountability have extensive practical implications for implementing source separation of waste. Propositions 2-

4 suggest that IoT systems can enable the accountability of waste generators (residents) and waste collectors, as well as supporting and enabling positive interaction between their respective accountabilities. The case studies show that it is technically feasible to trace the households which dispose of bagged rubbish in a residential community and to hold them accountable for their waste disposal behaviour. In the past, there lacked an efficient means to identify noncompliant citizens with regard to correct source separation of household waste. However, the advancement of IoT technology could be a game-changer to enforce accountability in household waste source separation. Similarly, the IoT system enables the accountability of waste collectors by providing real-time fill rate information to the waste management companies operating at the backend. The data generated by the IoT system would not only be useful in optimising the waste collection systems already in place, the data could also be used to design the new source separation projects as part of the nation-wide expansion of the proposed IoT-enabled source separation program.

The fifth proposition suggests that a combination of positive (i.e., reward) and negative (i.e., punishment) incentives should be applied to effectively and efficiently implement IoT-enabled source separation. Employing a "positive" or a "negative" reinforcement approach alone cannot fully achieve the desired outcome. For example, Shanghai City in China recently started to enforce the very stringent "*Regulations on the Management of Household Waste*" from the 1st July 2019. An individual may be fined 50 to 200 RMB, and an organisation may be fined up to 50,000 RMB for an infringement of the regulation. On the 1st July, 623 organisations were fined in Shanghai (Xinhaunet, 2019). The determination of the Shanghai government is commendable. However, the Shanghai government faces the key challenge of identifying non-compliant citizens. The long-term effectiveness of using punishment alone to enforce source separation also remains questionable. In light of the case study findings, an IoT-enabled HWM system can help to accurately and efficiently identify non-compliant citizens. The researchers recommend a combination of a “positive” and “negative” reinforcement approach in the early stages of implementing IoT-enabled accountability, which is more likely to achieve a long term and sustainable change in the waste disposal behaviours of the public.

Lastly, the sixth proposition suggests that all the involved stakeholders must cooperate to play their roles in order to sustain the IoT-enabled source separation programme over the long term. Despite having a long history of piloting various source separation projects and promoting CE nationwide, the Chinese enforcement of environmental regulations has been considered weak (Farooque et al., 2019a; Zhang et al., 2019). With the introduction of IoT-enabled accountability for source separation, the Chinese government and policymakers now have a reliable and robust evidence base on which they can confidently enforce legislation on compulsory source separation. It is now time for the Chinese government to unify the waste separation and management standards, to make more strategic investments in supporting infrastructure and systems, and to develop specific guidelines and educate the public about them. The resulting changes would have significant impact on China’s sustainable development. Of course, there is a need for policy-makers to consider potential privacy issues in IoT-enabled applications to secure data and channel accesses to prevent the misuse of data (Al-Turjman and Alturjman, 2018).

Residential communities and their estate management need to play an important role in enforcing source separation. With the rapid progress of urbanisation in China, more and more people have moved to cities, where they live in residential communities. Their estate management bears the responsibility of managing the household waste that is discarded. They charge the residents a fee for their services. However, their traditional role is simply to coordinate rubbish collection by the waste management organisations and to keep the estate clean and tidy. The sorting of rubbish, if done at all, is undertaken by local waste management organisations. To implement an IoT-enabled source separation mechanism, the estate management needs to be equipped with IoT technology and deploy manpower to monitor residents' compliance in practising source separation. They also need to tailor training programs, awards, and penalties for their estates to optimise the likelihood of successful implementation.

Waste management organisations need to shift their operational focus from landfills to value recovery from waste based on CE philosophy. Because about 60% of the household waste is food waste, there will be a great need to invest in food waste treatment facilities after implementing source separation. These facilities need to be capable of using food waste to generate biogas, organic fertiliser, and protein feed. It is advisable for waste management organisations to collaborate with a wide range of industry sectors to maximise value recovery. As an example, textile materials may be recycled to produce insulation products for the construction sector (Nasir et al., 2017).

6. Conclusions

Many countries have faced serious challenges in managing ever-increasing household waste. The challenges are especially difficult for developing countries due to rapid urbanisation and population growth. Source separation in line with the philosophies of CP and CE is a best practice for sustainable waste management. However, it has been little practised in China and many other developing countries due to complex issues with infrastructure, culture, environmental education, and the public's waste disposal habits. The lack of accountability for these habits has been a major obstacle to enforcing source separation by the households which dispose of rubbish. This research addresses this challenge by investigating the role of IoT technologies in some of the most recent source separation projects, which have achieved considerable success.

In establishing the concept of IoT-enabled accountability by studying multiple cases of innovative use of IoT technologies in very recent years in China, this paper offers a number of original contributions. Earlier studies on source separation in China focused on the inhibiting factors which undermined many earlier pilot projects; comparatively, this research reveals the reasons for success in some of the more recent projects. Earlier studies have also reported IoT-enabled traceability applications, but the use of IoT to achieve accountability in managing human behaviour is a new research topic, which warrants further studies. Furthermore, this paper advances six theoretical propositions which explain the multiple dimensions of IoT-enabled accountability.

This study's results have significant practical implications. IoT-enabled accountability in HWM contributes towards the development and adoption of CP technologies for improving environmental sustainability. The results of this study are of global significance because more and more countries are grappling with the challenge of HWM. The underlying mechanism of IoT-enabled accountability that is demonstrated by the case studies outlined in this paper offer guidance to other countries that are facing similar challenges in reshaping their citizens' waste disposal behaviours.

This paper has its limitations, of which one is its narrowed focus on accountability. Although lack of accountability is a key barrier to a successful source separation program, there are many other barriers that also need to be overcome, including issues in infrastructure and legislation. There is scope for future studies to investigate such other relevant factors. Moreover, the context of the study is limited to China. Given that waste disposal behaviours are influenced by culture, it is worthwhile to broaden the scope of the research to different cultural contexts. Future studies should also investigate ways of determining the ideal levels of reward and punishment in order to reshape people's behaviour effectively. A reward that is too small will be insufficient to change people's behaviour, while overly generous rewards will lead to excessive costs in the long run. Quantitative research is required in the design of the right reward/penalty scheme in order to elicit the desired behaviours.

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Supplementary Data: Sources of Cases A – D

Case A *Ningbo 2D barcodes*

	Source	Type	Language	Available at	Publication time	Main contents
1	China.com.cn	Central Government News Website	Chinese and English	http://zjnews.china.com.cn/yuanchuan/2016-03-03/59135.html	4 March, 2016	● Coverage of domestic waste sorting collection in urban area of Ningbo this year will reach 70%. ● QR real-name registration system covering the whole of this year is expected in August with the QR kitchen garbage bags into the thousands of households
2	People.cn	Central Government News Website	Chinese	http://zj.people.com.cn/n2/2017/0407/c186327-29986020.html	7 April, 2017	● The quality of performance of HWSS in Ningbo increased around 20% due to the implication of 2D barcode system since 2015.
3	CCTV.com	Central Government News Video	Chinese	http://news.cctv.com/2017/04/10/VIDEbqkxVHI6arPlf2j885Ef170410.shtml	10 April, 2017	● The quality of performance of HWSS in Ningbo increased around 20% due to the implication of 2D barcodes system since 2015.
4	Shanghai Xinmin Evening News	Newspaper	Chinese	http://xmwb.xinmin.cn/html/2018-09/20/content_12_2.htm	20 September, 2018	● Ningbo City ranked top 3 in HWSS Evaluation among 46 main cities in China. ● Introduction to the HWSS process in Ningbo ● How to use 2D barcodes in HWSS and the requirements for residents in Ningbo
5	Cnnb.com.cn	Local government website	Chinese	http://www.cnnb.com.cn/xinwen/system/2019/06/20/030061151.shtml	13 June, 2019	● Regulations of Ningbo Municipal People's Government on classification management of household waste
6	Zhejiang News	Local Government News Website	Chinese	http://zjnews.zjol.com.cn/zjnews/nbnews/201906/t20190613_10325453.shtml	31 June, 2019	● 2D barcode can trace to each house. ● Violation behaviors in HWSS will get punished. ● First ticket for violation was issued in Ningbo.
7	Cnnb.com.cn	Local government website	Chinese	http://news.cnnb.com.cn/system/2019/08/02/030073603.shtml	2 August, 2019	● Problems and future directions in HWSS in Ningbo City
8	zjol.com.cn	Local News Website	Chinese	http://zjnews.zjol.com.cn/zjnews/zjxw/201910/t20191029_11270990.shtml	29 October, 2019	● AI and camera technologies are engaged in HWSS in Ningbo
9	*Zhengce Liaowang*	Journal	Chinese	Article Title: Ningbo City has Achieved Periodical Progress in HWSS	2019(8): 29-31.	● The achievements and measures in HWSS in Ningbo City.

						● The use of 2D Barcodes in HWSS.
10	Cnnb.com.cn	Local government website	Chinese	http://news.cnnb.com.cn/system/2020/06/11/030160825.shtml	11 June, 2020	● One case of violation in HWSS is under investigation and prosecution. ● The violator was sourced with the 2D Barcode system.

Case B *Beijing smart waste separation system*

	Source	Type	Language	Available at	Publication time	Main contents
1	Cnr.cn	Central Government News Website	Chinese	http://pic.cnr.cn/pic/yc/20170815/t20170815_523901340.shtml#2	7 April, 2017	● Trial running of Intelligent waste separation in Beijing – East – City ● Points can be engaged to exchange rice and sesame oil.
2	The People's Government of Beijing Municipality	Local Government	Chinese	http://www.beijing.gov.cn/zhengce/zhengcefagui/201905/t20190522_60749.html	10 November, 2017	● Opinions of the general office of Beijing Municipal People's Government on accelerating the classification of domestic waste ● Beijing municipal solid waste classification and treatment action plan （2017-2020）
3	Beijing Evening	Newspaper	Chinese	https://www.takefoto.cn/viewnews-1753785.html	10 April, 2019	● How to use the intelligent waste source separation bin. ● Waste collectors can receive the full-load warning to timely empty the containers. ● The future widespread plan.
4	The Beijing News	Newspaper	Chinese	https://www.sohu.com/a/306964820_114988	10 April, 2019	● The functions of the intelligent waste separation bin. ● Interview speech from one vice director in the local Street office.
5	xinhuanet.com	Central Government News Website	Chinese	http://www.xinhuanet.com/info/2019-04/11/c_137967326.htm	11 April, 2019	● Introduction to the first intelligent waste source separation bin. ● Residence can register the HWSS by using smartphone app, or getting barcode card.
6	Sohu.com	National News Website	Chinese	https://www.sohu.com/a/308689734_677843	18 April, 2019	● The weighting and alarming function of the intelligent waste bin. ● HWSS whole process supervision system.

7	The Beijing News	Newspaper	Chinese	http://www.chinanews.com/sh/2019/07-06/8885713.shtml	6 July, 2019	● The usage of Intelligent waste bin by local residents in five communities ● Fully coverage of HWSS, and different ways of earning points.
8	Standing Committee of Beijing Municipal People's Congress	Local government website	Chinese	http://www.bjchp.gov.cn/cpqzf/xxgkzl/fdzdgknr/lzyj/zj63/sgzjd65/5291985/index.html	27 November, 2019	● Regulations of Beijing Municipality on the administration of domestic waste ● The first local law on domestic waste in China.
9	The Beijing News	Newspaper	Chinese	http://www.xinhuanet.com/politics/2020-05/05/c_1125942761.htm	5 May, 2020	● Specialized inspection on HWSS in Beijing City ● The problems existing in HWSS in Beijing and the responses and further instruments.
10	Bejing Daily	Newspaper	Chinese	http://www.cac.gov.cn/2020-05/21/c_1591608628870329.htm	21 May, 2020	● AI technology is engaged in Beijing's HWSS ● New intelligent waste bin with the functions of auto-sourcing, auto-sensing, auto-classification etc.

Case C *Sichuan smart recycling system in Chengdu*

	Source	Type	Language	Available at	Publication time	Main contents
1	chengdu.gov.cn	Local government website	Chinese	http://gk.chengdu.gov.cn/govInfoPub/detail.action?id=98402&tn=6	26 April, 2108	● Implementation scheme of household waste classification in Chengdu (2018-2020)
2	Southwest today	Local new website	Chinese	https://www.jinrixinan.com/archives/13627.html	3 December, 2018	● Introduction to the "Panda" HWSS and "IoT +_ Intelligent Recycle" mode in Chengdu.
3	Sichuan Daily	Newspaper	Chinese	http://scnews.newssc.org/system/20181214/000929613.html	14 December, 2018	● Intelligent waste separation bins are put into use in Chengdu City. ● Every household is allocated a 2D barcode, which is used for waste bags. ● Residents can get points and exchange for daily life articles.
4	e.chengdu.cn	E-newspaper	Chinese	https://e.chengdu.cn/html/2018-12/17/content_639975.htm#	17 December, 2018	● Introduction to the Intelligent HWSS system. ● Problems existed during the past 6 months' running.

5	Sohu.com	National news website	Chinese	https://www.sohu.com/a/327874631_100262126	19 July, 2019	● Introduction to the “Panda” HWSS recycle bins.
6	newssc.org	Local news website	Chinese	http://cd.newssc.org/system/20191206/002812887.html	6 December, 2019	● Introduction to the Intelligent HWSS system in Chengdu. ● The functions of the system includes auto weighing and auto-recording. ● Both 2D barcode and public transportation card are included in the system.
7	News.chengdu.cn	Local new website	Chinese	http://news.chengdu.cn/2019/0605/2053450.shtml	5 June, 2019	● Introduction to the “Internet + HWSS” mode in Chengdu.
8	People’s Daily	Central Government Newspaper	Chinese	http://paper.people.com.cn/rmrb/html/2020-01/03/nw.D110000renmrb_20200103_4-14.htm	3 January, 2020	● Introduction to the intelligent HWSS in Chengdu.
9	Sohu.com	National new website	Chinese	https://www.sohu.com/a/365336548_100027152	7 January, 2020	● Introduction to what’s the intelligent HWSS management and how to promote it in Chengdu?
10	Chengdu Daily	Local newspaper	Chinese	http://www.cdrb.com.cn/epaper/cdrbpc/202004/02/c59488.html	2 April, 2020	● Company’s actions in HWSS in Chengdu. ● How the 2D barcode and RFID technologies are engaged in HWSS in Chengdu.

Case D *Shenzhen smart household waste separation*

	Source	**Type**	**Language**	**Available at**	**Publication time**	**Main contents**
1	Shenzhen Evening News	Newspaper	Chinese	http://info.clean.hc360.com/2013/07/010942217161.shtml	1 July, 2013	● Shenzhen Municipal Solid Waste Classification Management Service Center is set up, which is the first one in China.
2	Suhu.com	National new website	Chinese	https://www.sohu.com/a/163146099_355807	8 August, 2017	● Introduction to the HWSS and intelligent rubbish bins in Luohu district, Shenzhen.
3	Guangming Ribao	Central government newspaper	Chinese	http://news.gmw.cn/2018-06/21/content_29368397.htm	21 June, 2018	● IoT technology in HWSS in Luohu district, Shenzhen.
4	Cankaoxiaoxi.com	National news website	Chinese	http://www.cankaoxiaoxi.com/finance/20170428/1944112.shtml	28 April, 2017	● Introduction to the “IoT + Community Intelligent HWSS” bin.

						● 2 barcode, GPS, temperature sensing, solar energy charging and other technologies are engaged.
5	sznews.com	Local news website	Chinese	http://www.sznews.com/news/content/2018-08/21/content_19913062.htm	21 August, 2018	● Comments from the residents on intelligent waste separation facilities in Shenzhen.
6	Shenzhen Evening News	Newspaper	Chinese	http://shenzhen.sina.cn/news/s/2018-12-20/detail-ihmutuee0867783.d.html?vt=4&fromsinago=pugeqsra	20 December, 2018	● The measures to handle household waste issue in Shenzhen.
7	Shenzhen City Administration Bureau	Local government website	Chinese	http://www.xhjjxh.cn/news/show-3-1404.htm	8 January, 2019	● HWSS in 2018 in Shenzhen City ● Achievements and problems in HWSS.
8	Sohu.com	National news website	Chinese	https://www.sohu.com/a/299421254_100014482	6 March, 2019	● Shenzhen Invest over 60 million RMB to build the first HWSS and intelligent collection project.
9	Sohu.com	National news website	Chinese	https://www.sohu.com/a/325110508_120060823	4 July, 2019	● Introduction to the intelligent HWSS system in Shenzhen.
10	cgj.sz.gov.cn	Local government website	Chinese	http://cgj.sz.gov.cn/ydmh/zcg/content/post_7900073.html	7 July, 2020	● Regulations of Shenzhen Municipality on classified management of domestic waste ● IoT, Intelligent and other technologies will be further introduced in HWSS.